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by

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Abstract

This paper explores different group decision making methods applied to the multi-criteria decision making problem of selecting a preferred "site" and develops a support system for group decision making. The group members consider sites to have alternative and often conflicting uses. It is imperative for decision makers in the responsible group to have an appropriate combination of tools, computer software, and decisions support systems in order to make the most preferred decisions as a group despite potential inherent conflict among members of the decision making group. To support this idea and facilitate decision making, this paper examines alternative group multi-criteria decision making (MCdecision maker) evaluation techniques, including: the Analytic Hierarchy Process (AHP), the AHP Combined Method, and the Group (self) Evaluation Method. A web-based comparison framework is developed to facilitate model use. These methods are applied to the evaluation of coastal zone sites for alternate marine use including aquaculture or fish farming. Aquaculture is one of the fastest growing activities among coastal nations. At the same time, companies, researchers, and coastal communities are seeking assistance in identifying appropriate coastal zone sites for commercial fishing and aquaculture activities, habitat reserves, and marine recreation. The aquaculture case study evaluates four possible fish sites in the Grand Manan Island area of Atlantic Canada.

Keywords: group decision making methods, the Analytic Hierarchy Process (AHP), web-based decision support system, site selection, aquaculture

Multi-Criteria Group Decision Making Methods and Integrated Web-Based Decision Support Systems

1. *Introduction*

Our minds have a limited capacity to assimilate and retain large amounts of information even for a short period of time. Due to such limitations and because in many situations sufficient data are not available, decision makers must base their decisions on information at hand and on the experiences they have accumulated over the years. The problem is how to assess the relative importance of multiple factors in order to define appropriate tradeoffs among them, and how to derive a system of priorities that can guide decision makers to make better decisions. To answer the question of good decision making in the face conflict, risk and uncertainty, the diversity of factors and varying interpretations of the options and judgments, a number of multi-criteria decision making techniques are examined. Each assumes that the problems involve complex choices requiring information, organization of thought, and the use of logic, intuition, and experience, and most often involve groups of decision makers.

When more than one decision maker is involved in a multi-criteria decision making problem, timing becomes an important issue. If the number of elements used to define the problem is large, collecting data from decision makers, organizing, analyzing, synthesizing, and finally reaching a conclusion becomes a tremendous effort. The use of technology can help to reduce the time that is spent on these issues. A visual and interactive decision making tool that is web-based, becomes an inevitable opportunity to assist in solving this problem.

Multi-criteria group site selection programs such as locating an aquaculture site in the marine environment is a particular MCDM interdisciplinary problem of interest that to date has not received attention in the literature. Determination of a preferred aquaculture site requires integration of data from various sources such as from ecological science to management science. Moreover, this complex decision problem involves groups of decision makers including federal scientists, industrial organizations, local communities, non-governmental organizations (NGOs), and provincial (local) government managers. All group participants seek solutions about preferred sites to locate an aquaculture site (or “fish farm”). Decision makers must take into account all aspects of the problem environment, e.g., the marine resources, habitat, effluents, and the benefits and cots of human-based activities. In this paper, alternative multi-criteria decision making aids are applied to the multi-criteria decision making for the case of site selection of new aquaculture fish farms. These methods facilitate group decision making by aggregating judgments of the decision makers in the groups. This paper introduces the multi-criteria group decision making problem, and the objectives and outline of the study for the case of aquaculture site selection in the marine environment located in the Grand Manan Island area of Atlantic Canada.

The Analytic Hierarchy Process, AHP (Saaty 1980) provides an effective means of dealing with complex decision making. AHP has been used in many application areas including site selection problems and group decision making. The importance of AHP, its variants, and the use of pairwise comparisons in decision making is best illustrated in the extensive references cited in the Saaty (1994) study. Chwolka and Raith(2000) applied AHP to analyze two different procedures for generating group decision support options. Their goal was to use AHP as a decision aid for the group as a whole, where the AHP result is treated as one single ‘decision-making body' ranking. Lai et al (2002) used AHP to select a multi-media authorizing system (MAS) in a group decision environment using the AHP software package, *ExpertChoice* where there are three MAS products and six software engineers as decision makers. The study compares two techniques: AHP and Delphi. Liberatore et al (1997) applied AHP in higher education where the alternatives are evaluated by group members. Malczewski et al (1997) proposed an integrated Multi-criteria Group Decision-Making Model, using AHP and an integer (0-1) mathematical programming method, for land suitability/use analysis in the Cape Region, Mexico. They used AHP to structure the problem and to incorporate the conflicting preferences of different interest groups into a formal procedure by using pairwise comparisons.

There are many articles and books written about the site selection decision problem. Bowen (1995) examined a comparison of AHP and PROSCAL for Nuclear Waste site selection decisions among thirteen potential sites for the nuclear waste repository derived from U.S. Department of Energy DOE. Monte-Carlo simulation compares the two methods in single decision-maker versus group decision situations. Eldin et al (2004) applied three integrated tools to determine the optimum site for a specific facility: AHP, Geographic Information System (GIS), and Expert System (ES). The authors suggest that by integrating two major tools (GIS and AHP), the user involvement and the level of the computer skills required are reduced.

The internet has become a powerful tool that enables researchers, decision makers, and managers to use it effectively in order to make better choices more efficiently. For example, the Click4DS (2007) decision support tool is a simple AHP web-based tool which provides decision support for specific problems e.g., selecting computer software or choosing a girlfriend/boyfriend using AHP. Web-HIPRE (HIerarchical PREference analysis on the World Wide WEB) is a Java-applet for MCdecision maker based on the decision support software HIPRE 3+ and announced as 'the first interactive MCdecision maker software on the internet' developed by Hämäläinen and Mustajoki (1998). It provides AHP in support of multi-criteria decision analysis. OPINIONS-Online (Hämäläinen and Kalenius, 2004) is an interactive tool that allows web-based group decision making, voting, and surveys. It can be accessed from anywhere with a Java enabled web-browser.

In response to the problems and the requirements for multi-criteria group decision making for the site selection problem, the purpose of this paper is to introduce, develop and apply a web-based integrated system for group decision making. The system is applied to the specific case of group participation in the siting of coastal aquaculture ventures in Atlantic Canada.

2. *Methodology*

Group decision making techniques and concepts are analyzed to examine how the suite of alternative decision support methods in a group setting provide rationale for resolving the group problem. Specifically, the following group methods are presented as representative of a wider set of methods: a) the AHP method; b) the AHP combined method; and c) the Group (self) evaluation method. These group multi-criteria decision making methods analysed below represent a subset of a wider set of methods toward development of the web-based group decision support tool for the site selection problem.

2.1 Analytic Hierarchy Process

AHP decomposes the MCDM problem into a hierarchy as presented in Figure 1.

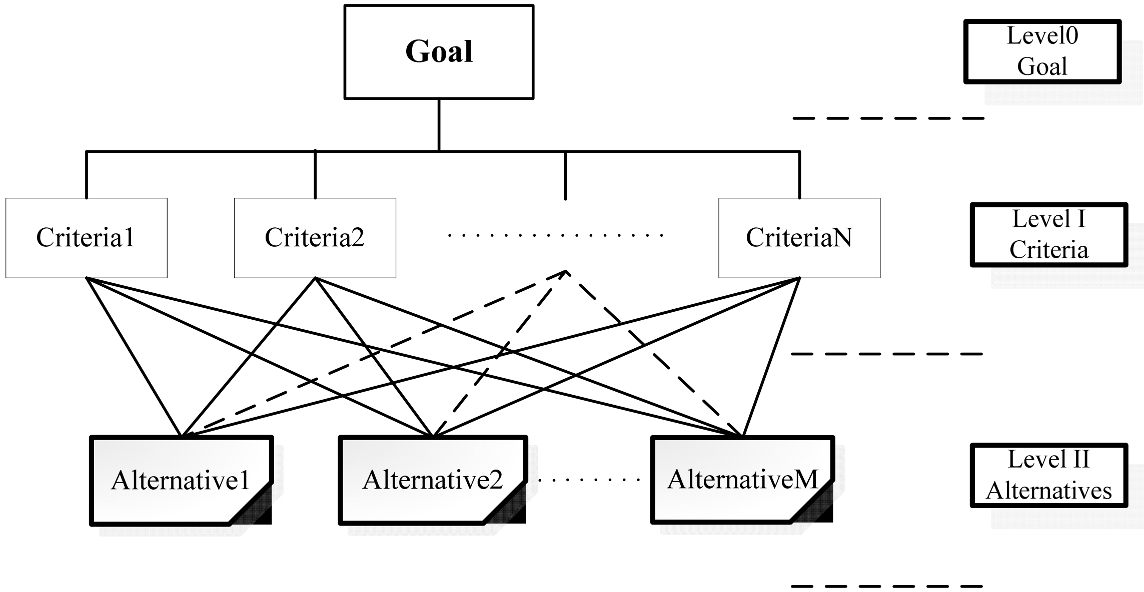

Figure 1: Analytic Hierarchy Process Design

AHP uses a numeric 9-point scale for quantitative and qualitative measurements (Saaty 1989). The AHP evaluation phase for individual members of the group is mainly divided into five steps as given below:

1. Develop a hierarchy describing the problem (Figure 1);
2. Generate pairwise comparison matrices for each level of the hierarchy by using 9-point scale and for each decision maker;
3. Generate the weights of the measures for each decision maker;
4. Normalize weights to get the consistency among measures for each decision maker; and
5. Calculate the overall rankings over the alternatives for each decision maker.

There are three possible situations for AHP group decision making (Moreno 2002). These are: i) Joint Action Group Decision - decision makers seek a common result by acting jointly as a single decision maker, e.g., equitable input weights; ii) Negotiated Decision - each decision maker argues or persuades others of their own judgment and then through discussion with the other decision makers achieves a common solution (e.g., Delphi method); and iii) Systematic Decision - each decision maker acts independently and a group result is a function of each member's independent output ranking of the alternative.

2.2 AHP Combined in Group Decision Making

AHP Combined is a form of Joint Action Group Decision. It provides several benefits. The more decision makers are involved in decision making, the more knowledge will be gained by all. If more than one person is affected by a decision, it is beneficial to have all those individuals involved in the decision process. By using AHP, each party is considered separately with respect to each criterion and, if required, with respect to each other. In general, the method of AHP Combined is appropriate for group decision support as a means of integrating the individual results of all involved decision makers.

In AHP Combined, the inputs are combined by using a geometric mean approach across all individual decision makers. The geometric mean is the n^{th} root of the product of the all members of the set, e.g.,

$$\left(\prod_{i=1}^{n} a_i\right)^{1/n} = \left(a_1 * a_2 * \ldots * a_n\right)^{1/n} \tag{1}$$

where n is the number of members, and a_{i} is the value of the i^{th} member.

As opposed to the arithmetic mean which yields the total value of n times the individual value if all the other data have the same value, the geometric mean calculates the individual value to the power of n if all the other data have the same value. Considering the outliers, use of the arithmetic mean may lie far from the median point. However, this problem is avoided with the geometric mean. In our study, each decision maker evaluates the criteria and the other decision makers with respect to the same criteria. The judgments are defined as multiplication, e.g., how much A is more or less important than B. The decision makers use this judgment to provide a pairwise comparison matrix. If the central tendency is violated, the geometric mean approach would fit better than using the arithmetic mean. However, if any member of a set is ‘zero’, then the calculation of the geometric mean may appear to be impossible. If such input happens, that value is set to ‘1’ in order not to lose the data and to result in a feasible solution.

2.3 Group Evaluation Method

In this approach, decision makers are evaluated as well as alternatives with respect their comparison to each other relative to each criterion. In the group evaluation, overall weights are applied to individuals’ results from the decision makers’ own feedback in the form of self-evaluation of the group members. In the first step, each decision maker evaluates the other decision makers, excluding themselves, with respect to each decision maker’s capability to evaluate the criterion by using pairwise comparison. In the second step, the weight of each criterion made by each decision maker is used to create Group Evaluation weights for each decision maker. As a result, there will be only one matrix for each of the criterion with the combined weight of decision makers. In the AHP model, each decision maker evaluates criteria with respect to criteria. The same weights are used in the Group Evaluation to get the overall weight of the criteria. To compute the overall priority of the decision hierarchy, each value of the criterion given by each decision maker is multiplied by the given decision maker’s weight. Summation of all the weights in a given row gives the overall score of the given criterion. Consider the step by step calculation:

Step1: Weights of the decision makers with respect to each criterion are calculated by using AHP pairwise comparison.

Step2: The weight of each criterion is computed given the assigned weight of each decision maker to the given criterion. AHP is used to calculate the weight of the criteria.

Step3: To get the overall priority of the alternatives in the group evaluation: the actual score of the i^{th} alternative by j^{th} criterion found in Step2 is multiplied by the weight of the given decision maker found in Step1. Summing each of the possible outcomes will be the result of the overall priority in the Group Evaluation method for each alternative,

$$A_{GE} = \max \sum_{j=1}^{n} a_{ij} \alpha_j \qquad (2)$$

where A_{GE} is the overall priority score for the alternative in the Group Evaluation model; a_{ij} is the actual score of i^{th} alternative in terms of the j^{th} criterion; and α_j is the overall weight of importance the j^{th} criterion.

2.4 Methods Critique

This section determines the use of each model, and critiques the similarities and differences of each for general application. Tables 1 and 2 present the strengths and the weaknesses of the group decision making methods analysed (Ozer 2007). This analysis is used to develop the method selection rationale of the Web-based decision support tool.

One of the main advantages of the AHP method is the relative ease with which it handles multiple criteria. In addition to this, AHP is quite easy for most decision makers to understand and it can effectively handle both qualitative and quantitative data. The use of AHP does not involve complex mathematics, but integrates subjective judgments with numerical data. AHP involves the principles of decomposition, pairwise comparisons, and priority vector generation and synthesis. A certain degree of inconsistency is allowed, which in most decision scenarios is realistic. The methodology of the AHP is similar to that used in common sense decision making. Users generally find the pairwise comparison form of data input straightforward and convenient. On the other hand, there are some serious doubts and weakness of the AHP. Increasing in the number of levels and number of pairwise decisions, increases the data requirements of the process. The discrete scale of one to nine does not take into account the uncertainty associated with the mapping of one’s perception or judgment to a single number. The scale is very useful to compare two elements at a time in a decision making process, however, precisely because the scale is subjective, it is subject to human error.

Method	Strengths	Weaknesses
AHP	Handles multiple criteria	Ranking reversal may occur in the presence of irrelevant alternatives
	Appropriate for group decision making	Data greedy and time consuming for problems with large hierarchies
	Demonstrably intuitive approach that doesn't involve complex math	Doesn't take into account potential uncertainty in data input
	A certain value of inconsistency is allowed and measured	Consistency is sometimes very difficult to maintain, especially for larger problems
	Easy to capture data and convenient to set-up and apply	
	Can combine qualitative and quantitative data	
AHP Combined	Simplifies the group pairwise comparisons to act as an aggregated single decision maker	Doesn't take into account potential uncertainty in data input
	Advantages of AHP (individual) apply to aggregated group input	Geometric mean sometimes leads to non-intuitive results, e.g., compared to simple weighted average of individuals
Group Evaluation	Self-evaluation among decision makers is informative	Doesn't take into account potential uncertainty in data input
	Reducing the noise by having decision makers weights	Data greedy and time consuming for problems with large hierarchies and large groups

Table: 1: Comparison of Group Decision Making Methods.

The AHP Combined approach used the geometric mean to aggregate individuals' AHP responses. This approach is meaningful since AHP requires having reciprocal logic. By doing so, the number of matrices for this method was distinctively reduced so the computation becomes easier than computing all the matrices separately.

The main advantage in the Group Evaluation technique is to be able to calculate the weights assigned to the decision makers by using the pairwise comparison approach. This technique gives a unique advantage over some other methods. Since each decision maker evaluates the other decision makers, the biasness of the weights is subsumed by the decision makers own feedback. For the sake of anonymity, no one is allowed to see the others' evaluation so this also eliminates biasness and none of the decision makers is affected by the other decision makers' decision. Every single decision maker is given a direct and important role in the evaluation process of the decision makers. That makes the technique very useful where it shows that the decision makers are satisfied with such a process instead of making an assumption about them e.g., equally important assumption. Apart from the advantages of the Group Evaluation Method, there are also some disadvantages. If a decision maker has a subjective perspective, then the result is subject to evaluator bias. If a decision maker has no experience in a given field, the evaluation of that decision maker with respect to given field may end up with a biased decision. Having a large number of criteria, sub-criteria and a large number of decision makers makes the process problematic, slow, inefficient in terms of time, and it accordingly may also be expensive. This technique may not be appropriate if time has an important role on the decision, specifically if all the calculations are done manually.

Method	Decision Makers	Input Requiremts	Process	Results
AHP	Individual decision makers; Can be treated equally; Data assumed precise; Uncertainty not considered	Pairwise comparisons over the decision hierarchy; Weights for criteria, sub-criteria; Some inconsistency allowed	Each decision maker's individual feedback as input; Generate pairwise matrices; Assign weights Check consistency Normalize weights	Individually preferred ranking Use individual analyses
AHP Combined	Can be treated equally; Decision maker's data assumed precise; Uncertainty not considered	Weights for criteria, sub-criteria Some inconsistency allowed	Generate pairwise matrices; Assign weights; Check consistency; Normalize weights; Apply geometric mean for input	Use combined analyses
Group Evaluation	Decision makers opinions treated equally; Eliminate equally important assumption; Evaluate decision makers and criteria	Weights for decision makers; Weights for criteria, sub-criteria; Some inconsistency allowed	Generate pairwise matrices; Assign weights; Check consistency; Normalize weights	Use individual analyses

Table: 2: Process Flow Table.

Table 2 summarizes the comparison of group decision making methods that are used in this study in terms of the needs of decision makers, input requirements, process, and results. The comparison of methods table (Table 1) and the process flow table (Table 2) are created to assist in the development of the web-based tool in order to determine the most appropriate method under different problem conditions. The web-based tool framework uses the two tables discussed above to define the most appropriate group decision making method based on a decision analyst's responses to leading questions.

3. *Web-Based Tool for Group Decision Making*

The web-based tool has been designed for group multi-criteria site selection problems, and specifically, for the application to the aquaculture case study. The following schematic figure, Figure 2, depicts the architecture of the Java, Java Script, MySQL, and Php application for the web-based tool. It illustrates the main components and data flows of the system and the architecture of the Php/JavaScript Net application for multi-criteria group decision making methods decision support.

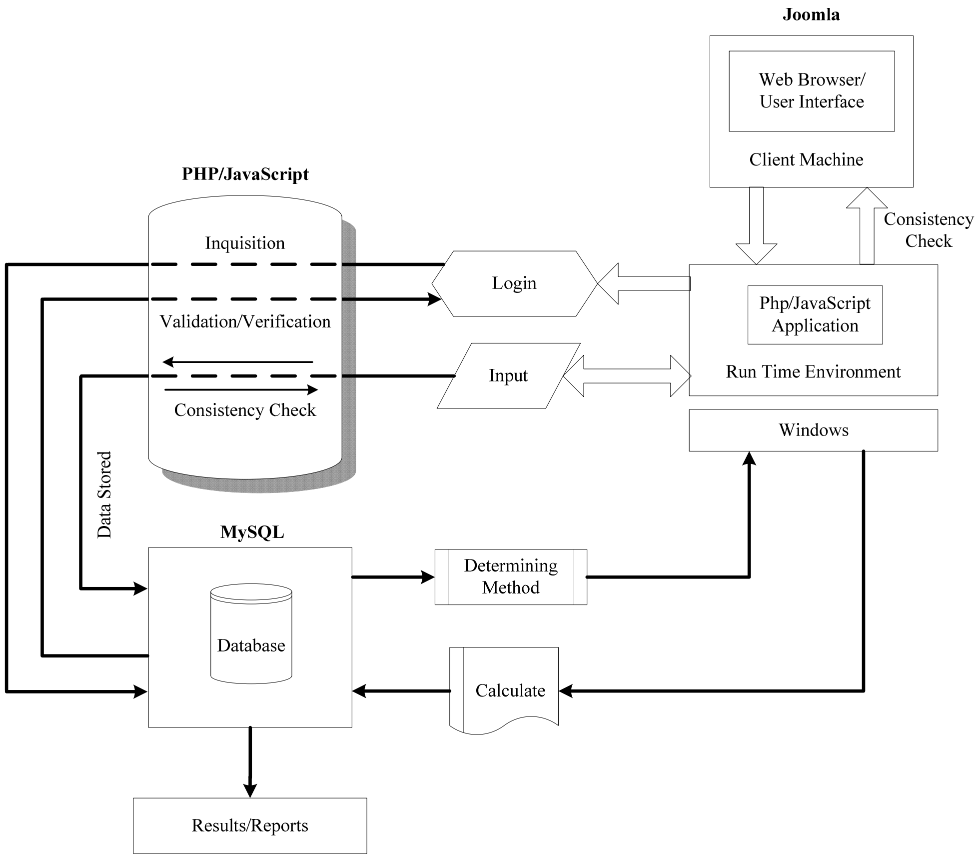

Figure 2: Architecture of the Php/JavaScript Net Application.

Figure 2 shows how the web-based tool procedes from user inquisition and validation/verification process, entering the pairwise comparison scores, checking for consistency, storing the data, etc. The web-based tool has been created by and is managed through open source Content Management System software, Joomla, (CMS 2005). The administrator of the application website manages the contents of the site and the interface through Joomla. In the above typical scenario, the active pages from the Run Time Environment evaluate the client's pairwise comparisons. On completion, the resulting hierarchy weights are delivered to the Web browser for viewing by the Administrator. Clients access the *Aquawebsite* from their own computers and enter scores directly on the page. However, clients do not see the calculation steps. On each page, clients have a user-friendly interface in which to enter their pairwise comparisons for the evaluation of criteria, sub-criteria.

Each client in a group is given a specific username and a password by the administrator in order to be able to enter pairwise comparisons. On entry to the *Aquawebsite*, the client's identification is tested in the database to check whether the username and the password of the client matches the stored information. Once the inquisition process is validated, the client enters pairwise comparison judgments in the system. The weights that are entered by clients are delivered to the server and stored in the MySQL database. Once the pairwise comparison judgments are entered, JavaScript determines whether the stored data for each matrix provided by the client is consistent. If there is an inconsistency, the system reports the inconsistency of the specific matrix/matrices to the client. The client is then asked to revise the stated pairwise comparisons.

MySQL is also an open source package and popular for web applications. It is used as the database component of the platforms. In the web-based application used in this study, the Php platform is used on the web server to collect data that are entered by the decision maker clients and are then sent to store in the MySQL database (MySQL 2006).

JavaScript is used to develop the application in order to check the consistency of each pairwise comparison matrix provided by the decision makers. It is the most popular and versatile scripting language on the Internet (JavaScript 2005). It is used to create menus, to validate forums, and to improve the design and much more. JavaScript is used to check the consistency of the matrices. If any inconsistency occurs, the system reports the inconsistency issue to the decision makers with a note to revise the pairwise comparisons of the relevant matrix. However, due to the large number of matrices used in the aqua case study, a certain level of inconsistency is accepted. The current level is set to 0.1. Php is used to calculate the most preferred alternative by using the most appropriate method based on information about the problem context and the decision makers. Php helps the decision analyst to determine which group decision making method is most appropriate for a given problem based on real-time responses to queries about the problem and the decision makers. In Figure 3, the execution environment of Php/JavaScript Net Application is used in the run-time environment to carry out the required calculations and results based on the responses to the key queries that lead to identifying the most appropriate group method. Once all the pairwise comparison judgments are entered by each client, the results and reports become available for the Administrator/Decision Analyst. The decision makers are able to modify their preferences. However, they are not authorized to see the other decision makers' judgments. Once the decision analyst answers the key questions, the web-based tool then provides the most suitable method and its ranking results. The rationale for method selection is presented below.

3.1 Method Selection Rationale

The basic concept involved in the selecting of a group decision making model is based on the problem context scenario, and the needs of the decision makers to the specific method. Ozer (2007) examined the selection of the best location for a problem with three decision makers and four criteria to demonstrate a practical case with group decision making. *Aquawebsite* is designed to provide a tool to visualize and perform the full range of group decision making methods in a valuable quantitative analysis. There are two aspects to conceptualize in the method selection: i) the methods comparison, and ii) the process flow. The decision diagram, Figure 3 illustrates the conceptualization of the method selection rationale.

The numbers in Figure 3 represent specific questions asked sequentially of the decision analyst. Responses to the questions narrow down the appropriateness of each method for the given problem situation. The questions are used to assess the conceptualized method based on the nature of the decision makers and the type and context of the problem.

The first question in Figure 3 distinguishes between whether the "information content" assigned weights (inputs) by the decision makers are assumed to be certain, or whether they should be considered to be more uncertain in their pairwise comparisons:

Question #1- Information Content: Are the decision makers generally certain about the information content of the decision or there should the information on comparisons be considered as vague or uncertain?

Rationale: If the response to this first question is “Yes” (inputs are generally more certain), then this immediately eliminates the fuzzy group methods (Fuzzy AHP, Fuzzy AHP Combined, Fuzzy AHP Group); if “No”, (inputs are generally more uncertain) then this immediately eliminates other decision making methods that rely on more fixed data (AHP, AHP Combined, WSM, WPM, Group Evaluation).

The second question is whether or not for the given problem, the group decision making members should be considered as equally important to the resolution overall:

Question #2- Decision Makers Evaluation: Is it possible for the decision makers to evaluate each other?

Rationale: Decision makers may acknowledge specific expertise among fellow decision makers in the problem. Their inputs be weighted based on their inherent abilities in relation to the problem. For instance, if it is generally agreed that a particular decision maker of the group is an expert on “marine science”, then the other decision makers know that the expert should have more weight than that the others related to problem criteria involving “marine science”.

Third question is used to analyze the units of the decision problem:

Question #3- Scale of Measure: Are the units in the criteria/sub-criteria of the decision hierarchy the same?

Rationale: If the response and rationale to the answer to this question is “Yes”, then this immediately considers WSM (“Weighted Sum Method”) as a possible method with the others since WSM is applied to a problem where the units are the same; if “no”, then this immediately eliminates WSM.

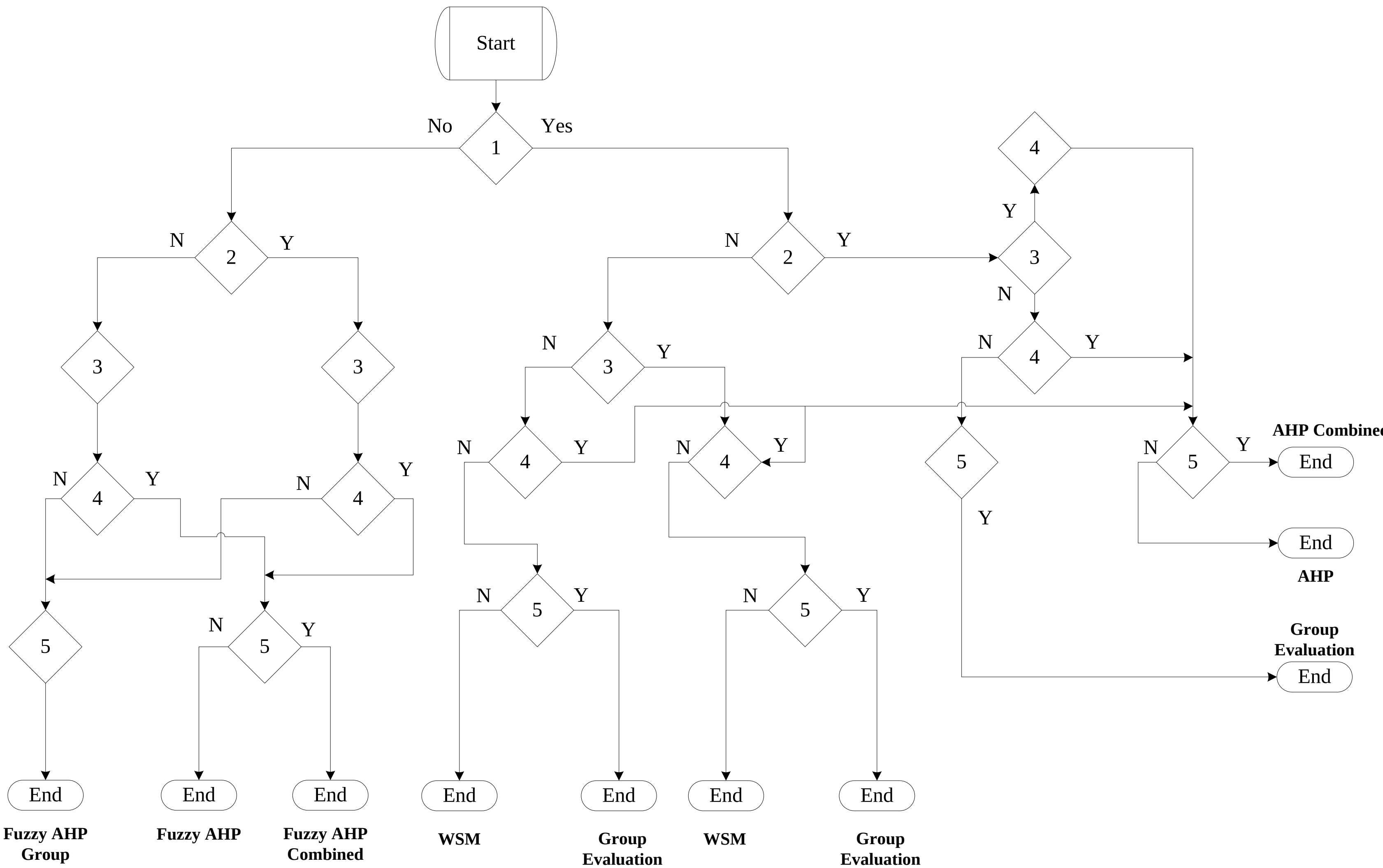

Figure 3: Conceptualization of model selection (Ozer 2007).

The fourth question attempts to isolate the importance of any one prominent deicison makers of the group. This question responds to the situation where one decision maker, e.g., the CEO, may carry more responsibility than other group members.

Question #4- Group Member Dominance: Is there at least one member of the decision making group who is weighted more highly than other participating decision makers?

Rationale: If the response and rationale to the answer to this question is “No” then this immediately eliminates WPM (“Weighted Priority Method”); if “Yes”, then this immediately considers WPM as one of the possible methods since there would be prominent decision maker among the group.

Finally, information on the ability of the decision makers to combine their inputs and achieve some level of input consensus is requested. In some group decision problems, the decision makers “agree to disagree” and may not be willing at the outset to negotiate or be subject to persuasion of their fellow decision makers.

Question #5- Negotiability: Is combining the assigned weights or inputs possible?

Rationale: If the response to this question is “Yes” (negotiating combined inputs is possible), then this eliminates non-combined methods so that the combined methodologies may be considered (e.g., AHP Combined, Fuzzy AHP Combined). The preferred method may be determined dependent on the combination of responses to *Question #1* and *Question #5*. If *Question #5* is answered ‘Yes’, and *Question #1* is answered as ‘Yes’, then the fuzzy group methods are eliminated; otherwise, the preferred method will be AHP Combined; if *Question #5* is answered ‘Yes’, and *Question #1* is answered as ‘No’, then the Fuzzy Combined is selected as most appropriate.

4. *Case Study*

The case study used in this paper focuses on the coastal zone of Grand Manan Island, New Brunswick situated in the Bay of Fundy. Since the 1980s when the aquaculture industry was established in Canada, production has increased rapidly from 36,462 tonnes of fish in 1990, to 155,634 tonnes of fish in 2003 (Statistics Canada 2006). Similarly, sales increased to $738.84CDN million of aquaculture products and services in 2005, from $447.3CDN million in 1997 (Statistic Canada 2005).

The main focus of the case is on the use of potential marine sites for the expanding aquaculture sector. Marine sites are opportunistic sites for other activities such as commercial fisheries, and reserves for recreation on natural resources. The objective of the case analysis is to develop a multi-criteria decision support system for the evaluation of marine sites by the multiple participants of the coastal zone in the decision-making processes involving coastal aquaculture. Figure 4 presents the case decision hierarchy.

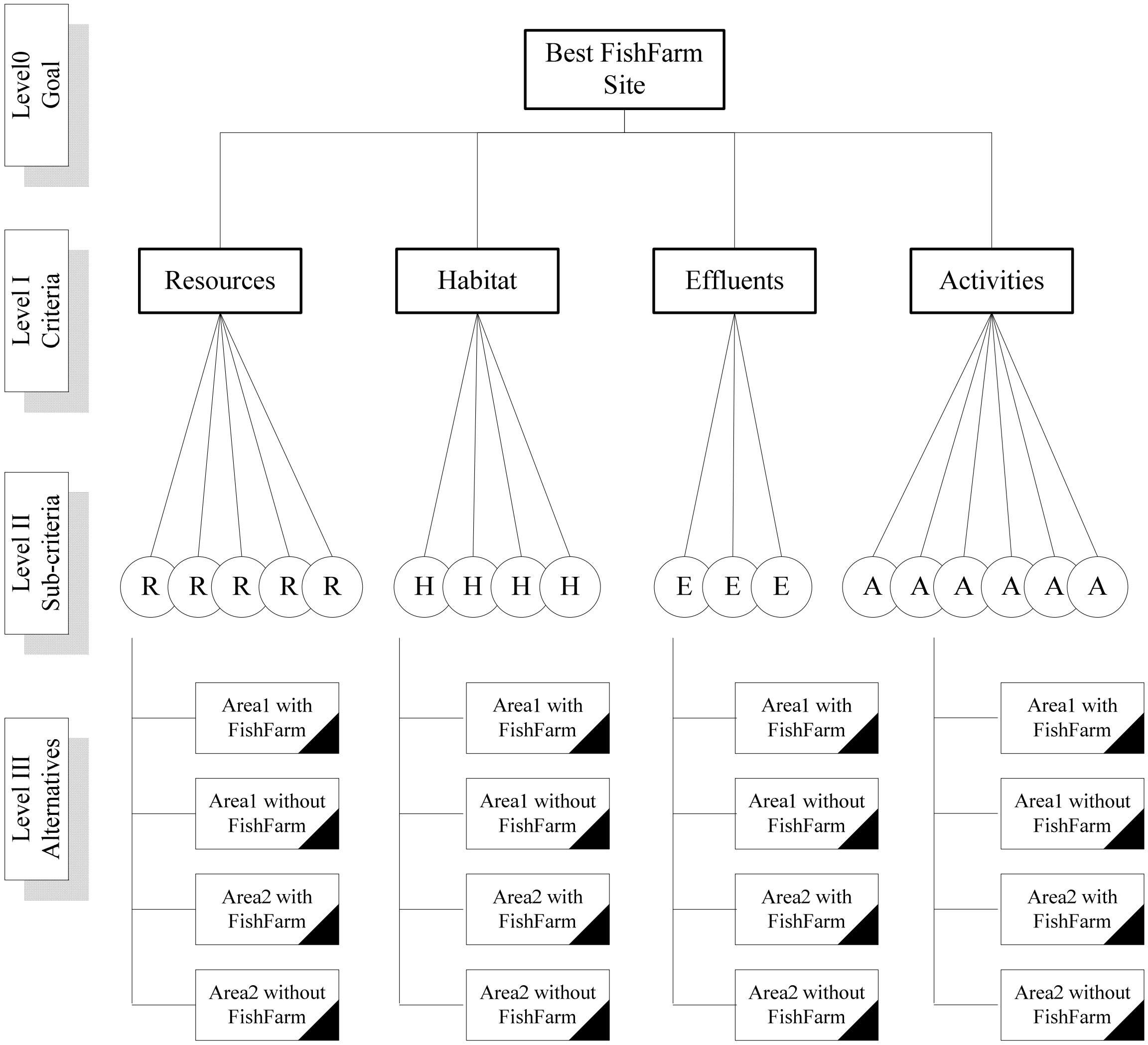

Figure 4: Hierarchical problem formulation of the case study.

Figure 4 depicts the aquaculture case decision hierarchy of the marine ecosystem criteria (4) and sub-criteria (18), and the sites alternatives (4). The sub-criteria for each criterion is given in Table 3.

Resources (R)	HerringDay, HerringNight, Lobster, Scallops, Urchins
Habitat (H)	Rockweed, SaltMarshes, CurrentFlow, BottomStructure
Effluents (E)	Coastal-based pollution; MarineActivity pollution; Natural pollutants
Activities (A)	HerringWeir, FishFarms, LobsterTraps, ScallopDrags, UrchinDrags, Recreational

Table 3: Sub-criteria table for each criterion.

Decision makers use AHP and pairwise comparison to compare each criterion in Level I, and each sub-criterion in Level II of the decision hierarchy. The decision making group members (5) are: (1) Federal Scientists, (2) Provincial Governments managers, (3) Non-governmental Organizations (NGO's), (4) Industrial Organizations, and (5) Local Communities leaders (including Native Peoples).

There are two selected marine areas for possible site selection by the decision making groups denoted as: Area 1, and Area 2. Each site's ecosystem impacts are evaluated along the 18 dimensions of the decision hierarchy sub-criteria using GIS (Zhao et al 2005) to obtain the ecosystem yield evaluations with and without fish farms. The site alternatives evaluations are fixed for all decision makers.

4.1 Case Study Inputs

The inputs of the decision makers for the case study were obtained through the *Aquawebsite* application presented above. The decision makers entered their preferences in the tables for each criterion and sub-criterion of the decision hierarchy. Similarly, the group self-evaluation data was obtained with respect to criteria, and sub-criteria. There were three decision makers identified as representing each of the 5 decision making groups. Decision makers' feedback within the same group membership were consolidated (using the AHP combined, geometric mean calculations) into a single input entry representing the membership. The following *Aquawebsite* application screen dumps show the inputs for only one decision maker, a Federal Scientist, as an illustration.

Figure 5 shows the pairwise comparisons of criteria and sub-criteria for one Federal Scientist. For example, in Level I, according to the Federal Scientist, Habitat and Resources are judged to be between "equal" and "moderately more important" (value 2) compared to Effluents in the siting problem, and "moderately more important" (value 3) than Activities. The comparison of sub-criteria used in Level II are also provided in Figure 5.

Figure 6 shows the queries for the group method selection. After the decision analyst answers all key questions and clicks on the 'Evaluate' button, the system provides the most preferred method based on the rationale of Figure 3. An example of the selected most appropriate method for the aquaculture dataset is given in Figure 7 below.

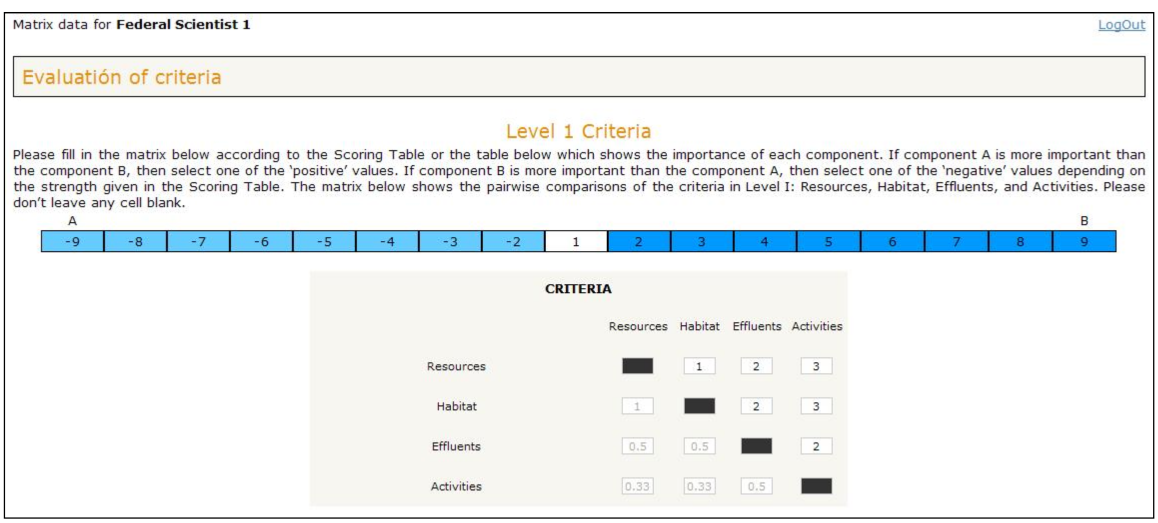

Figure: 5: Screenshot for the inputs of criteria and sub-criteria for the Federal Scientist1.

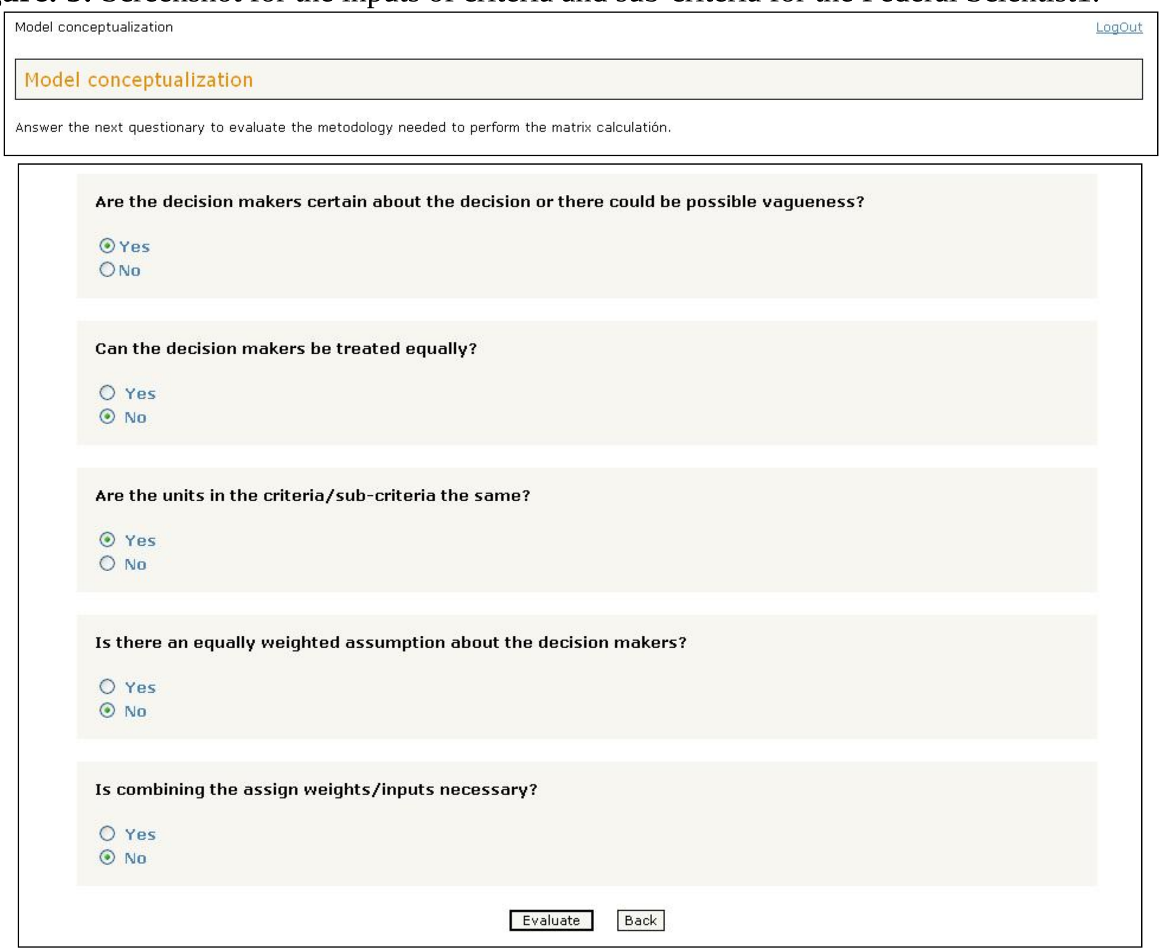

Figure 6: Screenshot of the questions for the Conceptualization of Model Selection.

Figure 7 shows the method selection “AHP Combined” as the most appropriate group decision making method for the aquaculture case study.

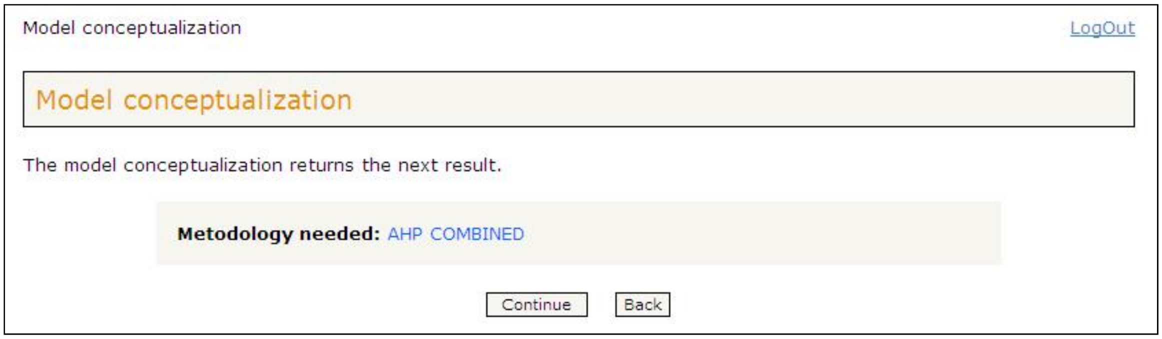

Figure 7: Screenshot of the selected model for the Conceptualization of Model Selection.

4.2 Case Study Analysis and Results

The overall duration of the evaluation of criteria, sub-criteria and decision makers input data collection was exhaustive for all methods and was quite a long process. The AHP Combined approach and the need for pairwise comparison is time consuming given the number of decision makers and the levels, criteria, and sub-criteria of the hierarchy.
The following tables show the outputs obtained using the web-based tool for the case study and the AHP Combined results. The complete data set of data for all methods provided in Ozer 2007. In the tables below it is noted that: FS is Federal Scientists, PG is Provincial Governments, NGO is Non-Governmental Organizations, IO is Industrial Organizations, and LC is Local Communities decision makers.

Criteria	**FS**	**PG**	**NGO**	**IO**	**LC**	**Priority**	**Scaled Priority**
Resources	0.383	0.289	0.388	0.384	0.289	0.355	0.341
Habitat	0.314	0.176	0.369	0.19	0.271	0.276	0.265
Effluents	0.174	0.09	0.086	0.088	0.087	0.131	0.125
Activities	0.129	0.445	0.156	0.338	0.354	0.281	0.270
	1	*1*	*1*	*1*	*1*	*1.043*	*1*

Table 4: Pairwise comparison matrix weights for the scaled priority of the criteria in Level 1 of the decision hierarchy for the five decision making groups.

Table 4 shows the individual AHP priorities and the overall AHP Combined priority of the criteria. For example, according to the Federal Scientists, Resources is the highest criterion with 0.383 among the other criteria. However, according to the Local Communities, Activities is the highest criterion with 0.354. Overall scaled priority shows that Resources is the highest criterion with 0.341 among the other criteria in Level 1. Activities are the second ranked criterion with 0.27, Habitat is the third highest criterion with 0.265, and Effluents is the lowest weighted criterion with 0.125, overall.

Table 5 shows the scaled priority matrix of the alternatives with respect to criteria for the Federal Scientists as an illustration. The complete data priorities matrices for all the other decision makers are found in Ozer (2007).

Fed.Sci	**R**	**H**	**E**	**A**
A1FF	0.109	0.499	0.261	0.196
A2FF	0.401	0.00002	0.239	0.324
A1NoFF	0.093	0.500	0.261	0.155
A2NoFF	0.399	0.0001	0.239	0.325

Table 5: Alternatives priority matrix of each criterion for the Federal Scientists.

The above table shows the priority of the criteria (Level I) for Federal Scientists. For example, according to Federal Scientists, A2FF is the best alternative with respect to Resources having highest priority weight 0.401; A1FF is the best alternative with 0.499 with respect to Habitat, etc.

Table 6 shows the overall ranking and priority for selecting the best alternative, A2FF (Area 2 with Fish Farm). According to the decision maker groups, Area 2 with Fish Farm (A2FF) is the "best", highest ranking site location for the Fish Farms with 0.261. Area 2 without Fish Farm (A2NoFF) is very close to the AHP Combined highest ranking site with 0.2608.

	0.341	0.265	0.125	0.270	
	Resources	**Habitat**	**Effluents**	**Activities**	**Priority**
A1FF	0.103	0.499	0.253	0.179	0.2470
A2FF	0.405	0.000	0.247	0.342	0.2610
A1NoFF	0.088	0.500	0.253	0.138	0.2311
A2NoFF	0.404	0.001	0.247	0.342	0.2608

Table 6: Alternatives pairwise comparison matrix and overall result for selecting the best alternative in AHP Combined.

5. *Conclusion*

This paper presented an analysis for the use of group decision making support methods for coastal aquaculture siting decisions in the Bay of Fundy. The objective of this paper is to investigate how to determine and apply the most preferred group decision making method in the case study. The paper has two main aims:

1) to analyze multi-criteria group decision making methods by implementing on an illustrative problem in order to be able to determine the most preferred method; and
2) to develop a web-based tool for the case study to help the decision analyst select the most suitable group decision making method and then provide its results.

The assessment of suitable method is an important aspect of the investigations. In order to find the most suitable method, the research conducted for this paper set out to investigate how each method is used in order to identify their potential problems in terms of weakness and strengths that is based on the decision makers and the case study. However, there are number of methods that can be applied to multi-criteria group decision making problems. The methods used in this paper have been reviewed to determine how those methods may influence decision makers. The overall objective is to gather methodologies from the theory of multi-criteria decision making, with emphasis on group decision making. As a result, followings have become a direct guide to analyze multi-criteria group decision making methods in this paper:

i) understanding the rationality of the decision makers;
ii) considering uncertainty issues on the decision makers' preferences;
iii) evaluating the other decision makers;
iv) developing the approaches of the decision makers to particular situations; and
v) and finally differentiating between different types of problem situations.

It has been highlighted that the web-based tool presented here meets a need to synthesize the large numbers of inputs required for the analysis of the various group methods. The web-based tool is used not only to enter and store the data to obtain results, but also to explore the problem situation and the needs of the decision analyst in making a decision on behalf of all group members. Analysis is continuing on the interpretation and use of group methods in the context of the site selection problem.

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